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Modtaget

CONTROL OF POWER, LOADS AND/OR STABILITY OF A HORIZONTAL AXIS WIND TURBINE BY USE OF VARIABLE BLADE GEOMETRY CONTROL

The present invention relates to a design concept by which the power, loads and/or stability of a wind turbine may be controlled by typically fast variation of the geometry of the blades using active geometry control (e.g. smart materials or by embedded mechanical actuators), or using passive geometry control (e.g. changes arising from loading and/or deformation of the blade) or by a combination of the two methods. The invention relates in particular to a windturbine blade, a windturbine and a method of controlling a windturbine.

INTRODUCTION TO AND DESCRIPTION OF THE INVENTION

Almost all large wind turbines build today have pitch bearings at the blade root so that the pitch of the whole blade can easily be changed by activating the pitch mechanism. Pitching of the blade is used as a brake to stop the rotor but it is also used for power and load control in different ways. On active stall controlled turbines a relative slow variation of the pitch of the blades is used to adjust the pitch so that stall on the blade occurs at the right maximum power, but the pitch system is also active at low wind speed to maximise the power. On pitch controlled wind turbines the pitch at high wind is changed continuously, so that the maximum power is not exceeded. This is done by reducing the inflow angle to the blade when the wind speed is increasing. The pitch system is also used at low wind speeds to maximise the power.

Recently, new types of pitch regulated wind turbines also use the pitch system to reduce the dynamic loads, either by cyclic pitch or by individual blade pitch. Different input signals to the control system as e.g. the flapwise loading can be used.

Apart from this state-of-the-art control with blade pitching, control of power and loads by movable, small control surfaces have been proposed [2]. A 550 kW turbine designed by ZOND in USA used a partial span aileron system for control of power and rotor rotational speed, [1]. The aileron system is similar to trailing-edge flaps for aeroplanes. Gurney flaps attached to the trailing edge of the blades have as well been proposed and analysed [3] (cf. Figure 1 of [3]). The advantage of a small control surface is a possible faster response due to less inertia than if the whole blade is being pitched. One disadvantage of Gurney flaps is

however the increase in aerodynamic noise from the free ends of the Gurney flaps and from the gaps in the blade where the Gurney flap is positioned.

Within the aviation industry leading-edge droop and trailing-edge flap have been investigated and used. Examples of airfoil characteristics obtained by such devices are shown in Fig. 2 and Fig. 3 of [5]. It is the variation of the same effects that are desired with this new invention. Also, the aerodynamics of micro-air-vehicles have been investigated, where flexible airfoils have been proposed, [4].

Thus, in a first aspect the present invention relates to a windturbine blade comprising

- shape deformable airfoils sections wherein the outer surface of each of the shape deformable airfoils sections is substantial continuos in all of its shapes,

and

- actuator means for providing the shape changes in the shape deformable airfoil sections.

It is envisaged, that the invention may render it possible to control the aerodynamic forces substantially instantaneously and locally along the blades of a wind turbine rotor by continuous variation of the airfoil geometry in the leading edge and trailing edge region along part of or along the whole blade span. In preferred embodiments, this is enabled by a blade structure consisting of a stiff load carrying part in the central part of the airfoil and a deformable leading edge and/or trailing edge region. The connection between the load carrying part and the deformable part should preferably be continuous, i.e. (there should be no edges, which can result in generation of noise). As mentioned in the section above, flaps, ailerons and gurney flaps have been used previously but have the disadvantage of causing discontinuities in the blade surface.

An example of a design based on the invention is the use of smart materials or by mechanical actuators integrated in a deformable materiel changing the outer geometry in the leading and trailing edge region and thereby changing the blade section aerodynamic forces.

In the following the term smart material is used. Within the meaning of this term is a material that deforms once a voltage is applied to it, such as the preferred material being

an active piezoelectric composite. However, other materials which deformation can be controlled actively is useable and preferred in connection with the present invention. The actuation of the deformable parts of the airfoil is controlled either actively passively or a combination thereof. The active control involves preferably a wind turbine control system monitoring loads, vibrations and/or stability, preferably by blade inflow measurements, flow pressures, strain gauges and accelerometers on different components providing input signals for the smart materials or actuators which then almost instantaneously change the geometry of the airfoil sections and thereby the aerodynamic forces. The passive control comprises preferably changes in the geometry obtained from influence of blade deformation, e.g. a change in effective camber from blade flapwise bending or from pressure fluctuations from the interaction with the flow.

Preferred embodiments of the invention have been found capable of reducing the dynamic loading from shear in the mean inflow, from turbulence in the inflow and from dynamic loading arising from the eigen motion of the blades by control of the instantaneous aerodynamic forces along the blade. Also loads from tower influence may be substantially reduced. Preferred embodiment of the invention may also make it possible to reduce the aerodynamic noise by reducing the dynamic pressure variations over the airfoil, e.g. in the case of a blade passing through the wake of a tower.
The use of the variable blade geometry concept can be combined with full span pitch control. e.g. for use at blade start and stop, for regulation of power and loads as function of mean wind speed and for reduction of loads at extreme wind speeds at rotor standstill.

It is envisaged, that preferred embodiments according to the present invention may provide one or more of the following advantages:

- full continuity of blade surface during control actions, which will enable low aerodynamic noise and high aerodynamic efficiency
- fast response possible as deformable materials can be made with low density materials as they are not carrying the main blade loads
- different control actions along the blade is possible which e.g. can be used to reduce dynamic loads and suppress vibrations in different blade modes and thus improve the stability of the wind turbine
- easier transportation of the blades as the deformable geometry parts of the blades can be mounted at the final site

In the following the invention and in particular preferred embodiments thereof will be described in details with reference to the accompanying drawings in which:

Fig. 1 shows a sketch of an airfoil with a movable Gurney flap positioned at the trailing edge;

Fig. 2 shows lift vs. angle-of-attack with and without a leading-edge droop (from [5]);

Fig. 3 shows lift vs. angle-of-attack with and without a trailing-edge flap (from [5]);

Fig. 4 shows a sketch of an airfoil according to the present invention with continuous curvature and deformable leading and trailing-edge;

Fig. 5 shows a cross sectional view of an airfoil trailing edge according to the present invention:

Fig. 6 shows a cross sectional view of an airfoil trailing edge according to the present invention;

Fig. 7 shows a cross sectional view of an airfoil trailing edge according to the present invention;

Fig. 8 shows a cross sectional view of an airfoil leading edge according to the present invention;

and

Fig. 9 shows a cross sectional view of an airfoil leading edge according to the present invention: passive control of the movement by the blade deflection. The small-dotted lines show the trailing edge in a deflected condition. The arrows show the shear-movement of the material and the corresponding movements of the trailing edge.

In fig. 4 an airfoil section 1 having a deformable leading and trailing edge is shown schematically. The airfoil section 1 has an initial shape indicated by solid lines where the leading edge 10 and the trailing edge 12 is non-deformed and a deformed shape indicated by dotted lines where the leading edge and trailing edge are deformed into the leading edge and trailing edge indicated by numerals 10a and 12a in fig. 4. Furthermore, the airfoil section 1 comprises a non-deformable section 14 which is designed to carry the load produced by the airfoil section. As indicated in fig. 4, the deformations of the airfoil section 1 does not introduce any discontinuities in the outer surface of the airfoil section 1 which remains smooth during and after deformation.

In fig. 5, a cross section view of an airfoil trailing edge 12 is shown. Again, solid lines indicate the initial shape of the trailing edge 12 and the deformed shapes of the trailing edge 12a are indicated by dotted lines. The deformable trailing edge 12 is made of a flexible material, preferably rubber, having voids 20. The trailing edge 12 comprises a construction 22 to which a beam 24 made of smart material is attached. The construction 22 is bolted to the non-deformable section 14 and the beam 24 extends in the longitudinal direction of the airfoil section 1 from the construction 22 and to the vicinity of the rear stagnation point 26 of the trailing edge 12 as indicated in fig. 5. When energizing the beam 24 of smart material, the beam will deflect upwardly or downwardly depending on the polarization of the voltage thereby resulting in a deformation of its initial shape (the shape of the trailing edge where no voltage is applied to the beam).

In fig. 6, a cross sectional view of an airfoil trailing edge is shown. In this embodiment, the trailing edge 12 comprises a skin 26 of sufficient strength to resist the pressure from the surrounding fluid acting on the surface to avoid a deformation of the skin due to this pressure. The skin 26 is made of a flexible material (e.g. rubber) and is attached to the non-deformable section 14. A piston assembly 28 that can actively control the movement of the trailing edge controls the trailing edge's deformation. This piston assembly 28 is at one end attached to a structure 22 similar to the one shown in fig. 5 at a position close to the upper side of the airfoil. At the other end, the piston arrangement 28 is attached to the inner side of the lower side of the skin. Upon activation of the piston arrangement 28, e.g. elongation or shortening of the piston, the trailing edge will deform into a deformed shape where either the trailing edge is bend upwardly or downwardly. 12a in figure 6 indicate two such shapes. It is noted that a similar or even equal result may be obtained by attaching one end of the piston assembly 28 to the structure 22 at a position close to the lower side

of the airfoil and the other end attached to inner side of the skin on the upper side of the airfoil.

In fig. 7 a cross sectional view of an airfoil trailing edge is shown. The trailing edge comprises a skin 26 similar to the skin 26 of the embodiment shown in fig. 7. Within the skin 26 a sheet of smart material 30 is located both at the upper side and lower side of the airfoil. The sheet of smart material 30 can actively control the movement of the trailing edge by applying a voltage to it. The sheet of smart material 30 may also act as a reinforcement of the skin 26.

In fig. 8 a cross sectional view of an airfoil leading edge is shown. The leading edge is structural similar to the trailing edge disclosed in fig. 7. Thus, the skin of the leading edge is made of rubber and within the skin one or more sheets of smart material that can actively control the movement of the leading edge are situated.

It is envisaged, that the embodiments shown in fig. 6 and 7 may instead of being controlled by smart material be provided with a smart material beam or a piston similar to the embodiments of figs. 5 and 6.

Deformation of the deformable sections of the airfoil is controlled by utilising a control system comprising a computer system receiving input from sensors arranged on components of the windturbine and providing in response to the input, control signals to the actuators, e.g. the smart material 24 or the piston assembly 28 to effectuate a deformation in shape. The effectuation is preferably almost instantaneously resulting in an almost instantaneously change in the aerodynamic forces.

By simulation models for airfoil flow it is possible to compute the lift force and the drag force for a given inflow condition (inflow conditions are the magnitude of the inflow velocity vector and the angle from the inflow velocity vector to the airfoil chord line also called the angle of attack). Now for an airfoil with variable geometry airfoil the same calculation of lift and drag at the same inflow conditions can be made for small steps in geometry changes from one outer extreme geometry to the opposite extreme geometry. Next the calculations are made from a number of different inflow conditions which means a number of different angle of attacks. In this way a table is made of lift and drag for different angle of attack and different steps of geometry changes.

In a final control loop on an operating turbine the control system will at each time step calculate if an increase or a decrease in aerodynamic load is needed and by use of the above table the corresponding change in geometry is decided.

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CLAIMS

1. A windturbine blade comprising

- shape deformable airfoils sections wherein the outer surface of each of the shape deformable airfoils sections is substantial continuos in all of its shapes,

and

- actuator means for providing the shape changes in the shape deformable airfoil sections.

2. A windturbine blade according to claim 1, wherein the actuator means are(is) active means in the sense that they(it) provide(s) changes in shape by supplying them(it) with energy.

3. A windturbine blade according to claim 1 or 2, wherein each shape deformable airfoil section comprising a substantially non-deformable part and one or more deformable parts.

4. A windturbine blade according to claim 3, wherein the skin constituting the outer surface of the deformable parts is made of a flexible material, e.g. rubber, wherein the transition between the outer surface of substantially non-deformable part and the skin is substantially smooth, such as continuously and wherein the inner side of the skin being connected to the actuator means.

5. A windturbine blade according to claim 4, wherein the actuator means is(are) extendable piston device(s), typically and preferably being hydraulic, having one end connected to said skin and the other end connected to the substantially non-deformable part or a structure connected to the substantially non-deformable part.

6. A windturbine blade according to claim 5, wherein the extendable piston device(s) extends mainly in the cordwice direction and wherein the end being connected to said skin is connected to the lower side of the airfoil and the end being connected to the substantially non-deformable part or the structure is connected in the vicinity of the upper side of the airfoil or vice versa.

7. A windturbine blade according to claim 3, wherein the skin constituting the surface of the deformable parts is made of a flexible material, e.g. rubber, which is attached to the substantially non-deformable part and wherein the actuator means is situated within the skin.

8. A windturbine blade according to claim 7, wherein the actuator means is(are) material composition(s) which elongation(s) is(are) controllable by applied electrical current(s).

9. A windturbine blade according to claim 3, wherein shape deformable airfoil sections are made of flexible material(s), e.g. rubber, and wherein the actuator means is(are) an extendable beam(s) extending within the material(s).

10. A windturbine blade according to claim 9, wherein the extendable beam(s) is made from a material composition which elongation(s) is(are) controllable by applied electrical current(s).

11. A windturbine blade according to claim 1, wherein the actuator means are(is) passive in the sense that they provide(s) changes in shape as a result of movement of the blade, said movement being preferably torsion, bending and/or rotation of the blades.

12. A windturbine blade according to any of the preceding claims, wherein the substantially non-deformable part is a central part of the blade and wherein the one or more deformable parts are the leading edge and the trailing edge.

13. A windturbine having one or more windturbine blades according to any of the claims 1-12

14. A method of controlling the operation condition(s) of a windturbine comprising one or more blades each having shape deformable airfoil sections, said operation condition(s) being preferably the load on the blade(s), the power produced by the windturbine, air induced noise, the stability of the windturbine and/or the like; said method comprises controlling the shape of the shape deformable airfoil sections, wherein the changes in shape are performed so that no discontinuities are introduced in the surfaces of the airfoils sections.

15. A method according to claim 14, wherein each or some of the shape deformable airfoil sections comprise one or more of the features according to any of the claims 1-12.

16. A method according to claim 14 or 15, wherein the windturbine comprises detecting means for detecting the one or more operation(s) conditions, wherein the detected operation condition(s) is(are) input to a computer system comprising functionality determining shape deformations to be imposed on some or all of the deformable airfoil sections based on said input.

17. A method according to claim 16, wherein the detecting means are inflow measurements to the, blade flow pressure, rotor position and/or strain gauges, accelerometers or the like provided on one or more components of the windturbine, said components being typically and preferably the blade(s), the nacelle and/or the tower.

18. A method according to any of the claims 14-17, wherein a typical time scale for a deformation to be introduced in the deformable airfoil sections, is lower than the time for one rotor rotation, preferably lower than half the time for one rotor rotation, such as lower than one quarter for the time for one rotor rotation.

19. A method according to any of the claims 14-18, further comprising the step setting and/or altering the full span pitch of each blade.

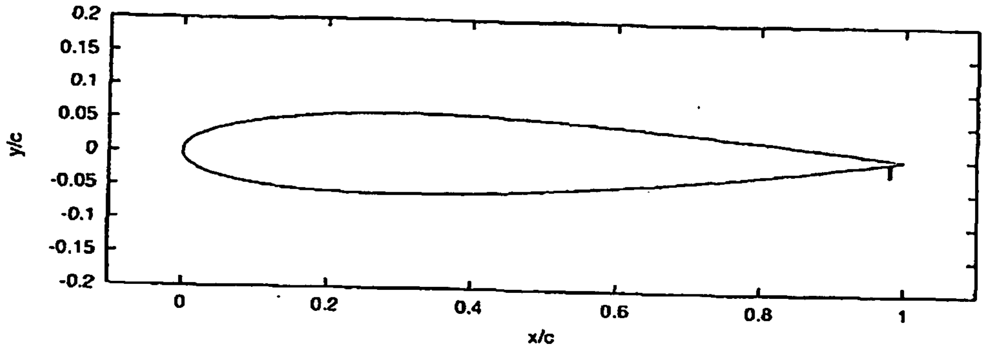

Figure 1

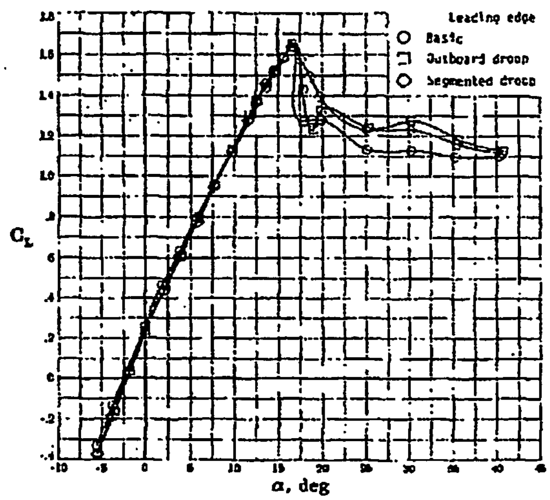

Figure 2

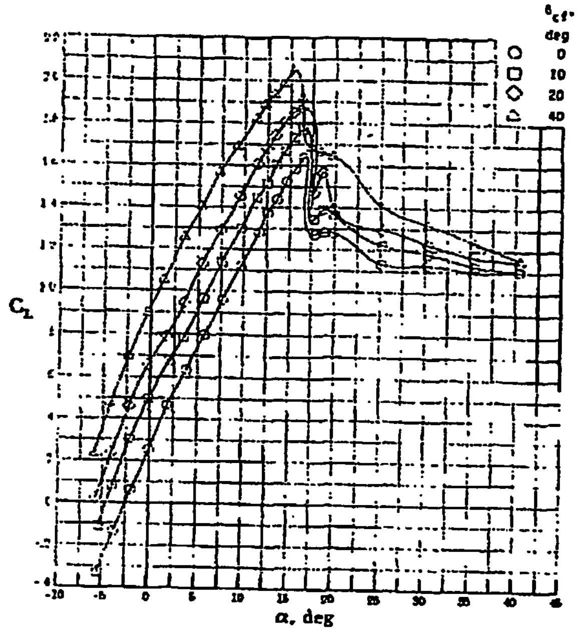

Figure 3

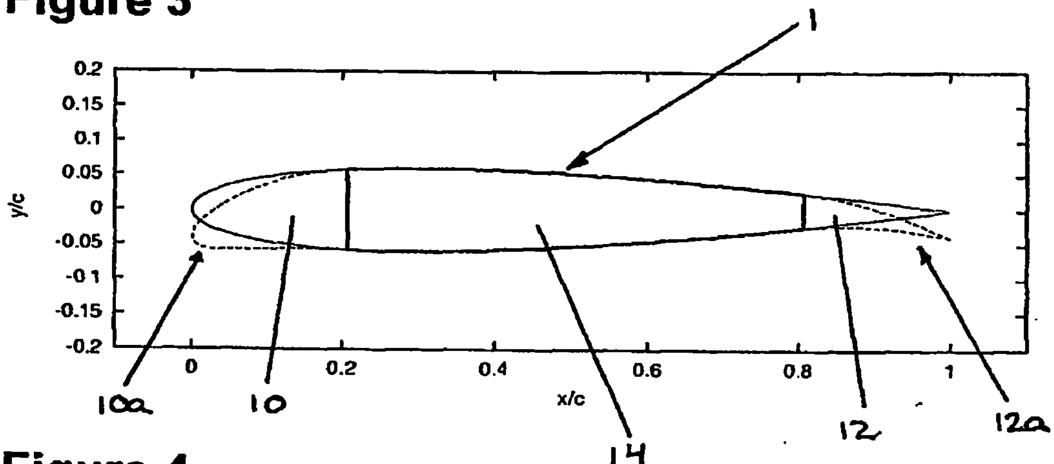

Figure 4

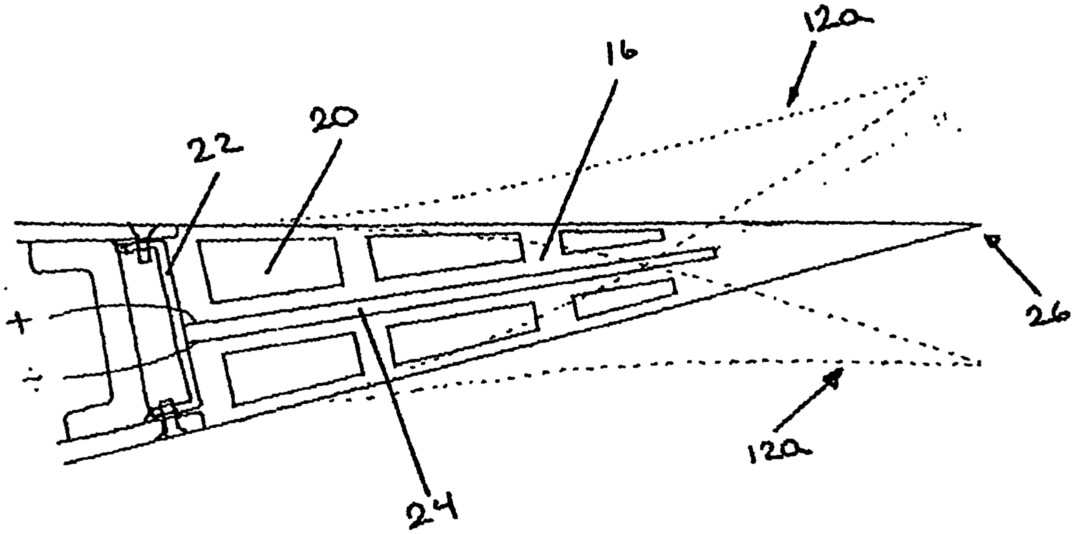

Figure 5

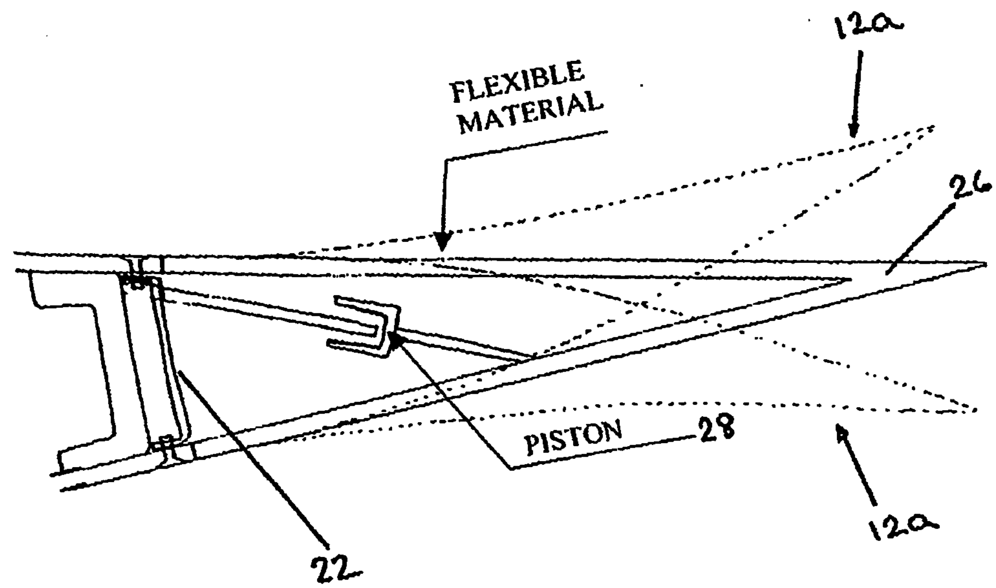

Figure 6

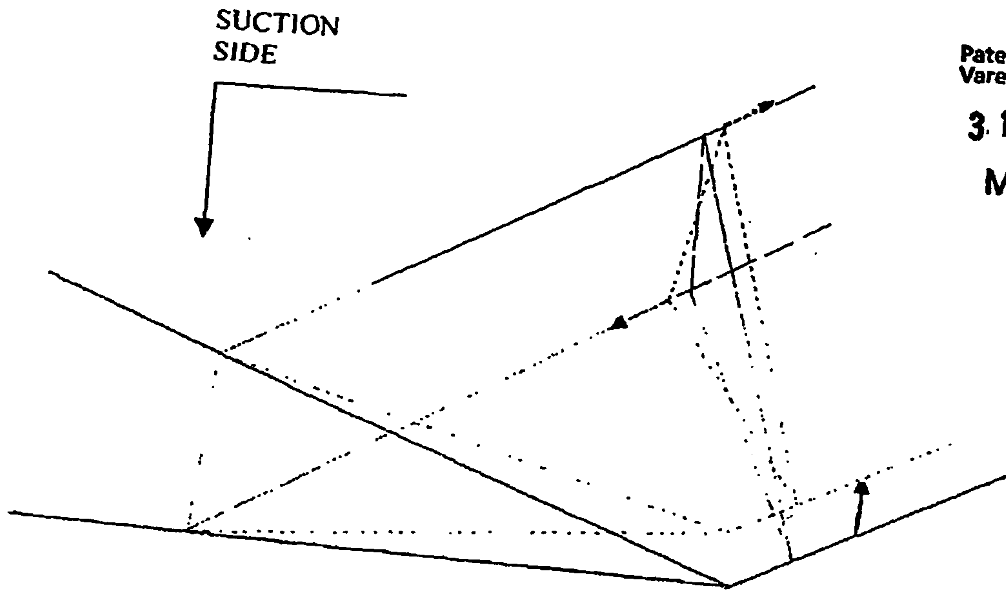

Figure 9